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STUDY ON COOLING MIST SPRAY CHARACTERISTICS AND CAVITATION INFLUENCE

AZWAN BIN SAPIT[1], MUHAMAD AKMAL HAZIQ BIN HISHAMUDDIN[2], MOHD AZAHARI BIN RAZALI[3], AKMAL NIZAM BIN MOHAMMED[4], MOHD FAISAL BIN HUSHIM[5], BUKHARI MANSHOOR[6] & AMIR KHALID[7]

Flow Analysis, Simulation and Turbulence (FAST) Research Group, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Malaysia

ABSTRACT

Spray or nozzle have many engineering applications, such as in combustion system, agriculture and industrial process, dust control, firefighting, spray drying and evaporative cooling. This research was carried out to study the spray characteristics of commercial water cooling mist sprays (nozzle diameter of 1mm and 2mm), and the effect of cavitation on the characteristics of the spray. The spray angle, droplet velocity and droplet size of each nozzles were taken by the means of direct photography using high speed camera and digital still camera. Next, cavitation phenomenon was simulated by CFD software (ANSYS) and its relation to the results from experiment was established. Results show that, the higher the supply pressure, the stronger the cavitation that occurs. This is shown by the value of minus pressure that generated inside the nozzle. This in turn effect the spray droplet size, where it is proven that higher supply pressure produced smaller droplets. Results also shown that with longer nozzle length, the cavitation can become more significant, until reaching certain threshold. This suggests that there is a relation of L/D (nozzle length to diameter ratio) that governs the cavitation formation.

***KEYWORDS:** Evaporative Cooling Spray, Droplet Size, Spray Cone Angle & Effect of Cavitation*

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Original Article

INTRODUCTION

Evaporative cooling is one of the efficient ways to bring comfort indoor and outdoor by cooling the hot air in the environment [1-2]. Through an experiment, they have verified the effectiveness of this method and confirmed temperature reduction [3-4]. Due to its simplicity, ease of operation and maintenance and low capital price, spray cooling becomes popular. Spray nozzles are used to help distribute water into the inlet air flow in order to provide a large contact surface area between air-water and to enhance mixing by producing very fine droplets. This offers higher evaporation rate and greater air cooling.

The concept of this spray is to produce small droplet of water or mist by applied pressure to the water reservoir. Water from the reservoir will flow in a tube then will go out through the nozzle installed.

Spray technique by is suitable for many application including cooling evaporative system. The usage and application of spray as a device for transportation (engine) [5], industrial and household purposes and has already proven such study on the matter is currently increasing.

There are several types of nozzle that can be used to produce the mist such as hollow cone, flat fan cone, full cone, spiral, and others, depends on the characteristics of the spray required [6]. As this study focus on the evaporation cooling mist spray, an actual commercially available single hole nozzles with different diameter were used.

METHODOLOGY

This experiment is conducted by using direct filming method for high speed camera (max video fps: 3000 fps) and short flash burst in dark room for DSLR (high resolution still image). In order to qualitatively and quantitatively analyze the spray characteristics, the proper post-processing of images is required. The entire images had been analyzing by using custom software. The experiment and analysis procedure is somewhat similar to previous study [7]. The water was supplied at pressure of 1, 2 and 4 bar, air humidity of 76% and at room temperature. The test rig representation used for this experiment is shown in Figure 1, and Figure 2 shows the two types of nozzle that was used in this study.

Study of cavitation effect was also made by the use of CFD software (ANSYS). This include geometry and mesh preparation, preprocessing setup, calculation (solver) and post processing. Results for experiment and CFD analysis will be shown and discuss in the next subchapter,

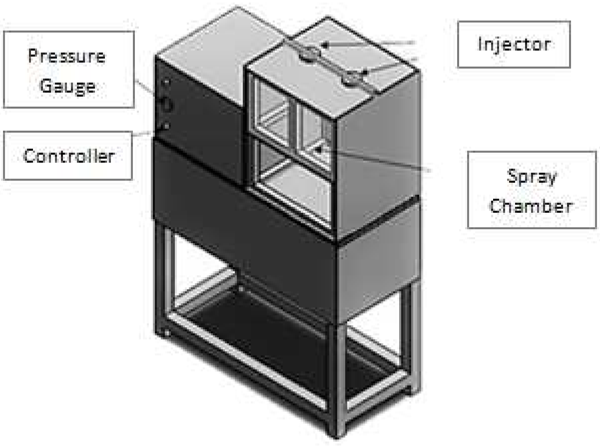


Figure 1: Test rig Setup Spray Image then Taken using DSLR and High-Speed Camera

(a) 1/8 SF-CE SM 1
(1 mm hole diameter)

(b) 1/8 SF-CE SM 2
(2 mm hole diameter)

Figure 2: The Two Type of Injector Used

RESULTS AND DISCUSSIONS

Spray Angle

Spray angle mainly determine the coverage area spray. It is defined by measuring the angle of the most outer section of the left and right boundary of the spray. The images of the spray formation were captured at water pressure of 1, 2 and 4 bar, air humidity of 76% and temperature of 27ºC by using High Speed Camera. Table 1 below shows the images of the spray formation for respected water pressure.

Table 1 and 2 shows the images acquired from the high-speed camera. Spray angle is then measured and the averaged value for 3 reading is calculated. Figure 3 shows the result of spray angle with different water pressure, and comparison is made between each nozzle spray angle. It can be seen that with the increase of water pressure from 1 bar to 2 bar, the spray angle increased for both nozzles. Interestingly, when the pressure was increased to 4 bar, the spray angle decreased slightly. This indicates that the probability of maximum spray angle for this nozzle is between 2 bar and 4 bar.

Table 1: Spray Angle (1/8 SF-CE SM 1)

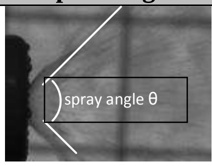
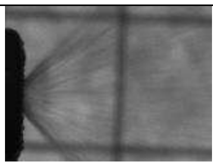
Pressure	Sample Image	Spray Angle θ
1 bar		108°
2 bar		112°
4 bar		107°

Table 2: Spray Angle (1/8 SF-CE SM 2)

Pressure	Sample Image	Spray Angle θ
1 bar		113°
2 bar		137°
4 bar		132°

When compared between nozzle, spray angle for nozzle CM 1 which has the smaller hole diameter (1mm), produce smaller spray angle than nozzle CM 2 (2mm). The spray angle difference is higher when water pressure increased. This is believed due to the nozzle geometry and design.

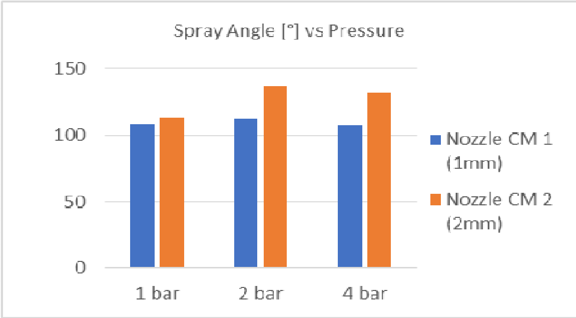


Figure 3: Changes in Spray Angle vs. Pressure

Droplet Velocity

Using the images from high speed camera and conducting frame to frame analysis, displacement of individual droplet can be measured. The result then divided by the time interval between frame to obtain droplet velocity. Results in Figure 4 show the average droplet velocity for respective nozzle with different water pressure.

Results show that when pressure increased, the droplet velocity increases. This is true for both nozzles. At water pressure 4 bar, the average droplet velocity exceed 10 m/s when compared to around 7 m/s at water pressure 1 bar. This is expected as with higher pressure, the water exited the nozzle with higher momentum thus the increase in velocity with water pressure. When compared between the two nozzle, there is a very slight difference in droplet velocity value, which is quite negligible.

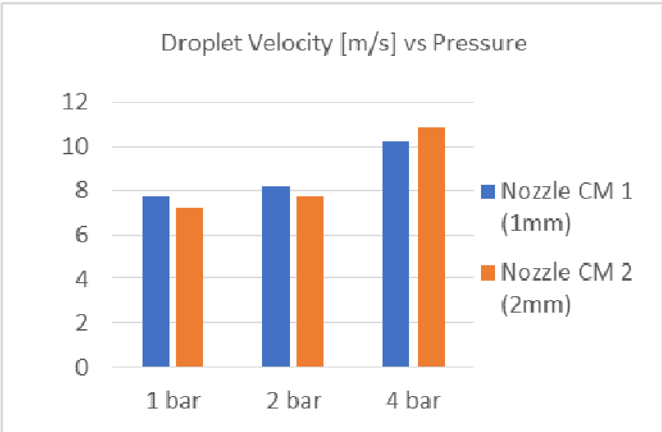


Figure 4: Changes in Spray Droplet Velocity vs. Pressure

Droplet Size

Using the high resolution still image, droplet size was able to be measured. Droplet size is an important parameter that usually will be taken into high consideration when selecting nozzle for the intended application.

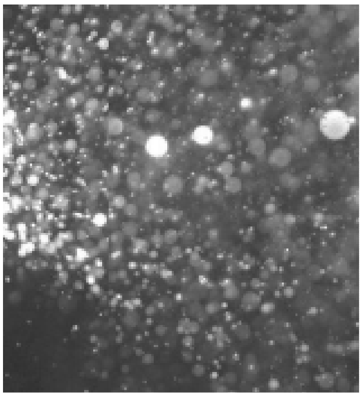


Figure 5: Sample of Still Image (Nozzle CM 1, 1 Bar Water Pressure)

Figure 5 shows still image sample taken by DSLR. By using telephoto (high zoom) lens, a high resolution still images of the spray droplet were captured. The image was the undergo post processing similar to previous study [6] to determine which droplets in the image that fulfill the requirement for measurement. Figure 5 shows image sample captured in this study.

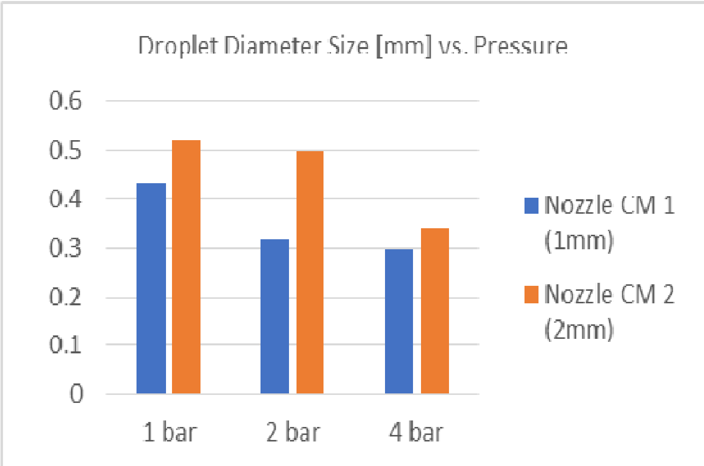


Figure 6: Changes in Spray Droplet Size with Pressure

Overall, there is clearly a decreasing trend in droplet size with the increase of water pressure as shown in Figure 6. This is true for both the nozzle. Interestingly, there is a notable decrease in droplet size for nozzle CM 1, especially at the higher pressure when water pressure was increased, but the difference is very little with nozzle CM 2. This suggests that although generally droplet size decrease when pressure increased, the decreasing trend is different for each nozzle.

Effect of Pressure on Cavitation

Table 3 and 4 show the lowest pressure observed inside nozzle for each L/D with variation in supply water pressure. It can be said that with increase of the water supply pressure, the minus pressure also increase, which would suggest that cavitation becomes enhanced. This conclusion is agreeable with the results from experiment, where, with when the supply water pressure increased, the spray droplet size decreased.

Table 3: Cavitation at 1mm Nozzle Diameter (Lowest Pressure Observed)

Pressure		1Bar	2Bar	4Bar
Nozzle diameter ∅ 1mm				
L/D	1	P_{min} = -40kPa	P_{min} = -85kPa	P_{min} = -170kPa
	2	P_{min} = -45kPa	P_{min} = -72kPa	P_{min} = -162kPa
	4	P_{min} = -33kPa	P_{min} = -70kPa	P_{min} = -164kPa

Table. 4: Cavitation at 2mm Nozzle Diameter (Lowest Pressure Observed)

Pressure		1Bar	2Bar	4Bar
Nozzle diameter ∅ 2mm				
L/D	1	P_{min} = -50kPa	P_{min} = -90kPa	P_{min} = -210kPa
	2	P_{min} = -60kPa	P_{min} = -120kPa	P_{min} = -256kPa
	4	P_{min} = -70kPa	P_{min} = -150kPa	P_{min} = -299kPa

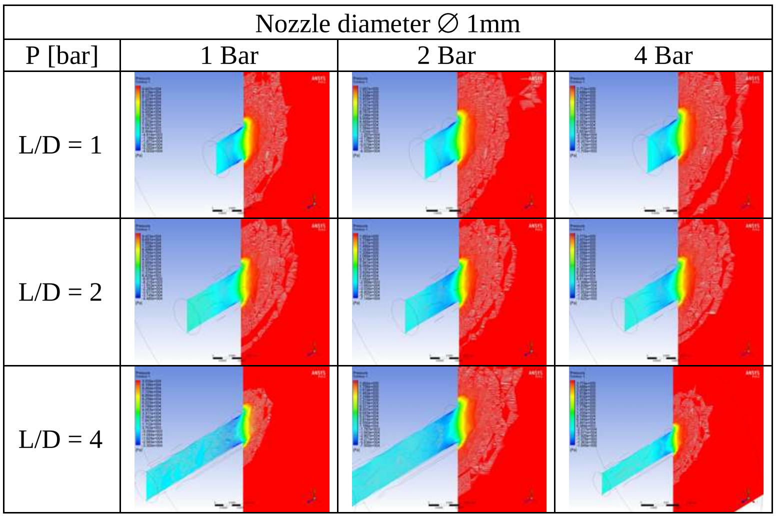


Figure 7: Pressure Contour for each L/D with Variation of Water Supply Pressure for Nozzle Diameter 1mm

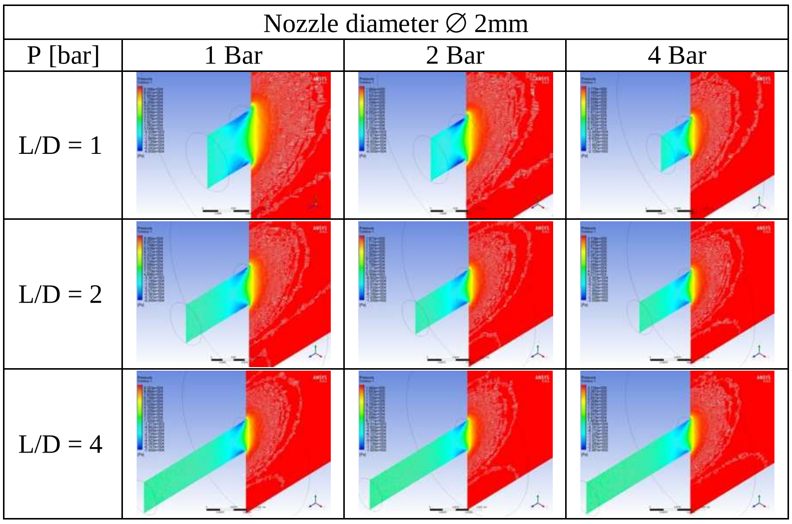


Figure 8: Pressure Contour for each L/D with Variation of Water Supply Pressure for Nozzle Diameter 2mm

L/D Relation

Figure 7 and 8 show the internal pressure contour of the nozzles for each L/D with variation of water supply pressure. Cavitation region which form at the neck of the nozzle, can be seen clearly indicated by the blue colored region (low pressure). The cavitation region continued to expand along the wall of the outlet hole (tunnel) until it diminished naturally, and with higher L/D value, the cavitation area are larger.

This cavitation phenomenon is believed to be among the reason of the ability of spray nozzle to produce atomization of liquid. Observing these results of pressure contour and pressure value (low pressure), it can be said that with the increase of L/D value, the cavitation is also becomes enhanced, which, in the end will affect the spray nozzle droplet size.

CONCLUSIONS

The objective of this study is to investigate the qualitative and quantitative characteristics of evaporative mist spray and the effect of cavitation has been achieved.

Results show that higher supply pressure will produce smaller droplet size. This is true for all nozzle diameter size. Higher pressure also generally increase spray cone angle and droplet velocity. All of these are favorable, as it will help better mixing with the surrounding air, and in the case of evaporative cooling, this will help to achieve cooling effect faster.

In reflect to the cavitation phenomenon, it is believed that cavitation is among the reason that promotes atomization. This can be said true as shown with the results that higher pressure produce lower pressure region (minus pressure) that acts as the cause of cavitation. In addition, the nozzle length to hole ration also play role in enhancing the cavitation effect.

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